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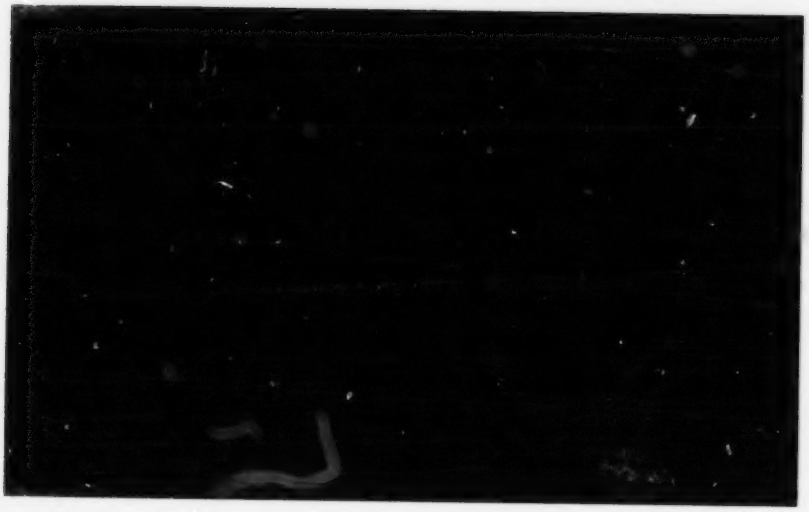

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A Statistical Analysis of Airline Accidents in Canada 1976–1987*

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1 Résumé

Dans de nombreuses études il a souvent été allégué que la déréglementation du transport aérien pourrait avoir un effet néfaste sur la sécurité. En effet, les transporteurs opérant dans des marchés de plus en plus compétitifs verraient leur rentabilité baisser et seraient tentés de diminuer la part budgétaire allouée à la sécurité. Aussi, l'arrivée de nouveaux transporteurs inexpérimentés et le trafic accru auraient un effet défavorable sur la sécurité aérienne.

D'autres études prétendent que les lois du marché en libre concurrence écarteraient du marché les transporteurs jugés dangereux. Une telle affirmation repose sur l'hypothèse selon laquelle le niveau de sécurité est une caractéristique observable et mesurable du produit offert. Cette hypothèse peut être violée de plusieurs façons; la part de responsabilité des transporteurs lors d'accidents ne peut pas toujours être établie avec certitude, le niveau d'effort et de ressources alloués à la sécurité ne sont, en général, connus que des transporteurs et il est connu qu'il existe un problème de perception des risques par le public lorsque les probabilités de pertes sont faibles.

Dans de telles circonstances, il a été montré qu'il est préférable, du point de vue du bien-être collectif d'utiliser à la fois la responsabilité, la réglementation et l'incitation économique afin que les transporteurs atteignent le niveau de sécurité jugé optimal. Pour y arriver, le *responsable de la sécurité aérienne* doit être en mesure d'identifier les facteurs qui influencent la sécurité afin d'évaluer la portée des différents outils de contrôle dont il dispose.

Dans cette optique, notre étude tente de relier les accidents des transporteurs aériens au Canada à leur situation financière ainsi qu'à l'environnement dans lequel ils évoluent. En

effet, les principales causes connues d'accidents aériens (défaillances techniques, conditions météorologiques défavorables et erreurs humaines) peuvent bien souvent être reliées à des facteurs économiques; de trop faibles investissements dans les équipements et leur entretien peuvent être la cause de défaillances techniques, de lourdes dettes peuvent inciter les transporteurs à voler malgré des conditions météorologiques défavorables, les entreprises rentables sont en mesure de payer du personnel plus expérimenté, etc.

À partir des données opérationnelles des transporteurs canadiens (nombre de passagers, de passagers-km, de vols, types d'entreprises, etc) pour la période 1976–1987 couplées à des indicateurs financiers (revenus et dépenses, bilans) pour la même période nous avons estimé différents modèles économétriques et ce, sous différentes hypothèses (distribution de Poisson et binomiale négative). Nos résultats montrent que certaines variables représentatives de la situation financière des transporteurs sont significativement reliées à la distribution des accidents aériens. Ces résultats indiquent que, pour la période considérée, les niveaux de sécurité choisis par les différents transporteurs canadiens l'ont été en fonction de leurs situations financières respectives.

Mots-clés: sécurité aérienne, transporteurs canadiens, conditions financières, déréglementation économique, modèles économétriques, modèle Poisson, modèle binomiale négative, responsabilité, incitation économique.

2 Summary

The main objective of this study was to provide a statistical analysis of airline accidents in Canada. Another important objective was to propose a framework for the analysis of the optimal safety behavior of airlines.

Although technological change was an important explanatory factor in the increase in aviation safety over time, economic and human factors remain significant ingredients in the study of airline accidents. It is generally recognized that safety is best achieved through a combination of liability, direct regulation and economic incentives. In other words, in the presence of externalities and asymmetrical information on safety activities between airline managers and safety authority, free market competition is not sufficient to guarantee that carriers will produce the socially optimal level of safety or the level of safety that maximizes the welfare of society. But, more importantly, for our purposes, it is not clear that traditional regulatory policies are optimal when the regulator's knowledge about individual carriers' safety is limited. The problem here is that even though accidents and incidents are observed by the regulator, the private effort expended by airlines to reduce accidents is not perfectly observable. Thus, the regulator cannot be certain whether accidents or incidents were due to the human and technological factors observed in the investigation done by the safety authority or to the lack of diligent efforts made by airline managers.

In other words, is the regulator's observation of both accident and incident causes and other safety activities sufficient to exercise the desirable discipline or to create incentives to maintain the safety activities at the optimal level set by the Government? Or is it desirable that the regulator has access to other types of economic indicators such as carriers financial

variables that may provide information on their safety activities?

The preliminary results of this study do not provide a definitive answer to these difficult questions but show that some financial variables are significant to explain carrier accidents in Canada. These results were obtained when appropriate variables for risk exposure (hours, area) and other control variables (congestion, speed, technology) were introduced in an econometric model for count data.

Particularly, the econometric results indicate that both Flight Equipment Maintenance Expenditures (FEi) and Working Capital (WCi) variables have statistically significant effects on the accident frequency. This means that airlines' financial conditions affected their safety choices during that period. These preliminary results seem to indicate that Canadian carriers trade off safety with other activities in a period characterized by both strong regulation of aviation safety and economic regulation of the industry. The statistical results also indicate clearly that the Designated Northern Area (identified by the variable NORTH) represents a more dangerous region for flying and that the type of aircrafts (measured by the proxy SPEED) is a significant explanatory factor of airline accidents. Other control variables in the models such as time and hours flown are also significant.

Since the period of analysis ended in 1987, it is difficult to propose any strong recommendation for public policy based on the results of financial variables analyses, although they can be useful for the discussion of future modifications of the regulatory scheme on aviation safety in Canada. However, the results of the different models indicate that financial variables are sufficient to assume that airline accidents follow a Poisson distribution and eliminate the specification error implied by the Negative Binomial model. This means that financial variables

are important in order to understand the distribution of airline accidents and that they should be considered seriously in any discussion of safety regulation, particularly in an environment of asymmetrical information on safety activities between the regulator and carriers.

In many studies and forums, it has been indicated that economic deregulation of the airline industry might introduce a negative impact on safety. The traditional argument was that deregulation would reduce the profitability of air carriers and, consequently, carriers' safety budgets. The results of this report do not establish a strong statistical link between profitability (or operating margin which is a measure of profitability before capital expenses and taxes) and accidents, and show that other financial variables are more appropriate measures of the statistical relationship between accidents and financial conditions. They also show that, even in the different economic regulatory environments for the period studied, financial variables were significant.

The result from the NORTH variable indicates, without any ambiguity, that more attention should be focussed on the safety conditions in that area. The same conclusion applies to the SPEED variable, but more investigation is needed to determine, in detail, the types of aircrafts that are more safe.

Many extensions to this research are possible. They are discussed in the conclusion of the report.

Keywords: Aviation safety, Canadian carriers, financial conditions, economic deregulation, econometric models, Poisson model, negative binomial model, liability, economic incentives.

3 Introduction

The main objective of this study was to provide a statistical analysis of airline accidents in Canada. Another important objective was to propose a framework for the analysis of the optimal safety behavior of airlines.

Although technological change was an important explanatory factor in the increase in aviation safety over time, economic and human factors remain significant ingredients in the study of airline accidents. It is generally recognized that safety is best achieved through a combination of liability, direct regulation, economic incentives, education, and safety promotion. In other words, in the presence of externalities and asymmetrical information on safety activities between airline managers and safety authority, free market competition is not sufficient to guarantee that carriers will produce the socially optimal level of safety or the level of safety that maximizes the welfare of the society. But, more importantly, for our purposes, it is not clear that traditional regulatory policies are optimal when the regulator's knowledge about individual carriers' safety is limited. The problem here is that even though accidents and incidents are observed by the regulator, the private effort expended by airlines to reduce accidents is not perfectly observable. Thus, the regulator cannot be certain whether accidents or incidents were due to the human and technological factors observed in the investigation done by the safety authority or to the lack of diligent efforts made by airline managers.[1]

In other words, is the regulator's observation of both accident and incident causes and other safety activities sufficient to exercise the desirable discipline or to create incentives to maintain the safety activities at the optimal level set by the Government? Or is it desirable

[1] Technically, this means that exact causes of accidents are observable with noise by the Safety Board.

that the regulator has access to other types of economic indicators such as carriers financial variables that may provide information on their safety activities?

The preliminary results of this study do not provide a definitive answer to these difficult questions but show that some financial variables are significant to explain carrier accidents in Canada. These preliminary results seem to indicate that carriers trade off safety with other economic decisions. They were obtained when appropriate variables for risk exposure (hours, area) and other control variables (congestion, speed, technology) were introduced in an econometric model for count data.

The discussion in the following sections is organized as follows. Section 2 presents a basic framework for economic analysis of aviation safety and for the understanding of the different private and public incentives to safety. Section 3 is devoted to the data set of this study. We review the main steps undertaken to build the data set which contains economic, operational and safety information of Canadian carriers of levels 1, 2 and 3. The different sources of information, descriptive statistics, and the different variables retained for the econometric analysis are also discussed. Section 4 reviews in detail the methodology for the econometric analysis of count data models and Section 5 presents the main results of the study. A brief conclusion summarizes the main statistical results and proposes some avenues of future research, mainly to extend the period of analysis covering a more recent period. Some public policy issues are also discussed.

4 A Framework for Economic Analysis[2]

4.1 Literature Review

In many instances, Canadians can learn and benefit from U.S. experience, as it provides a testing ground where economic and regulatory policies are sure to culminate. This applies to the airline industry. Following the U.S. Airline Deregulation Act of 1978, much attention has been devoted, especially in the media, to the potential deleterious effects of increased competition on airline safety. In the United States, airline crashes have become news items, concerns about aging fleets have been raised, airport congestion and delays have been experienced by many travellers. The perceived deterioration of airline safety in the same country, both by the public and the pilots, has led economists to investigate the matter with more scrutiny.[3] A recent book Transportation Safety in an Age of Deregulation, edited by Leon N. Moses and Ian Savage of Northwestern University is devoted to the matter; it gathers pieces of analyses that address the issue.

Whereas the wave of deregulation has not fully extended to Canada, there have been a number of structural changes in the Canadian airline industry resulting from economic regulatory reform, increased competition, and reduced federal participation in transportation services. The impaired capability of the federal government to provide capital funds and/or the new federal policy on privatization forced Air Canada to go private, at least partly. In this new environment, safety issues remain of paramount importance to the federal government.

Notwithstanding the fact that technological change has been the most important factor

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2 This section is based on a previous report by G. Dionne, N. Fortin and R. Gagné (1990).

3 See Nance (1989), Moses and Savage (1989b), Rose (1990), Talley and Bossert (1990).

in the evolution of airline safety in the past 30 years, economic and human factors in using the best technology remain the weaker links in the chain of precautionary steps. It is thus essential to understand how the economic and regulatory environments influence these factors. It is generally recognized that safety is best achieved through a combination of liability, direct regulation economic incentives, education and safety promotion.[4] In other words, it is not evident that free market competition is sufficient to guarantee that carriers will produce the socially optimal level of safety. Safety and insurance requirements have been incorporated into the certification policy. Economic incentives are also thought to be important as some economic environments may foster management philosophies that undermine cautious practices. However, a precise model of how these factors interact in the context of airline safety still needs to be worked out; it is one of the objectives of this study. Such a model is necessary if sound regulatory practices are to be developed. It would help achieve the goal of the federal government of "maintaining and improving transportation safety while reducing the burden of regulations on the transportation industry".[5] The precise statistical analyses of factors contributing to accidents to be undertaken in this study will point out the relevant interactions to be included in a general model of airline safety.

This study identifies the significant economic factors influencing airline safety. Some studies have tried to argue that the market may discipline unsafe airline operations as these would curb demand. However, evidence supporting that line of argument was found to be tenuous.[6] Following a crash of a given carrier, positive changes in the demand of competing

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4 See, for example, Shavell (1984, 1987).

5 Withers (1989), p. 301.

6 See Chalk (1986, 1987), Mitchell and Maloney (1988), Borenstein and Zimmerman (1988) for econometric evidence.

carriers gave only a weak indication of a substitution effect. Also, whether or not crashes act as proper signals of a carrier's safety level to shareholders and travellers is a controversial issue. Crashes may be interpreted as random "rare" events by shareholders and travellers, especially when the responsibility of the carrier has not clearly been established. Problems of the public perception of low probability events may compound this effect.[7] The argument that crashes adversely affect the economic position of carriers and thus discipline unsafe airline operations is questionable. Statistical evidence shows that one occurrence does not significantly affect stock prices and potential demand. Moreover, when this is understood by airline managers, it may introduce some degrees of freedom in the choice of airline safety since the anticipated cost of accidents is lower.

Other analyses have tried to relate airline profitability and accident experience. They generally found no significant link between reduced profitability and a higher accident rate.[8] One study that included post-deregulation data found that these links were somewhat significant for smaller carriers.[9] This study will be discussed in detail in Section 5 along with our statistical results. Also, some statistical relationships between the financial status of a carrier and its safety performance, as measured by the level of satisfactory inspection, were reported.[10] This evidence was found while omitting the control of other factors that may influence inspection ratings and may be dubious. Despite mixed evidence, the many channels through which profitability and ensuing investments in airline safety may be related make this a fruitful avenue of investigation. It will be the one favored in the present study.

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7 See Hogarth and Kunreuther (1989).

8 See Graham and Bowes (1979), Golbe (1986), Rose (1990).

9 See Rose (1990).

10 See Advanced Technology (1986).

Some studies have investigated the link between a decrease in airline safety and the arrival of inexperienced new carriers. But safety levels, as measured by maintenance expenditures, percentage of satisfactory inspections, and near midair collisions, were not found to be lower for new entrants than for established carriers.[11] The increase in commuter traffic was proposed as another source of potential decrease in overall safety for the travelling public, since prior to deregulation the safety record of commuter carriers was substantially lower than that of the trunks. However, the safety record of U.S. commuter carriers showed a dramatic improvement following the 1978 safety revisions. Also, since commuter service implies fewer takeoffs and landings than between small communities and large hub jet flights, the risk for travellers to and from those communities has been reduced.[12] Because the Canadian market is much thinner than the American one, the influx of inexperienced carriers, with potentially lower safety records, has not been important in Canada, at least for carriers of levels 1 and 2. However, a great number of communities are being served by smaller carriers and their safety record has been surveyed.

Overall, U.S. studies found that increased competition in the airline industry did not adversely affect the level of safety. However, one of the major problems faced by these analyses concerns the measure of safety performance. Because fatal accidents are quite rare, they are a very imperfect measure of safety. They provide a very limited number of observations against which the statistical significance of explanatory factors can be tested. Results indicating no statistical significance are thus not particularly revealing. Accidents defined as occurrences involving injury to people or damage to property are relatively more

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11 See Kanafani and Keeler (1989).

12 See Oster and Zorn (1989).

frequent than fatal accidents but still quite rare. The number of U.S. air carrier accidents averaged about 30 annually in the 1980's according to FAA evidence. Near midair collisions may not provide reliable data as reporting is incumbent on crews and largely voluntary. On the other hand, the use of inputs-to-safety measures in many studies, such as maintenance expenditures and rate of satisfactory inspection, are problematic as well, as explained below.

This study improves on U.S. studies by constructing a model of the firm where the safety incentives and disincentives of different hierarchical levels are specified and their relationship to the profitability of the firm and to regulatory constraints is established. The model's predictions were tested using a more comprehensive data base than that used in U.S. studies. In effect, one of the primary goals of this study was to construct a data base that included a large number of accidents to alleviate statistical problems and to span a wide variety of carriers exhibiting different financial structures. The possibility of considering incidents as an additional measurement of safety was explored. However, the data were not found of satisfactory quality to undertake an extended econometric analysis.

In contrast to U.S. studies, the data base of this paper includes extensive data on the financial posture of the firms, which have been extracted from annual reports. It was thus possible to determine the profitability of the firms with precision. Debt/equity ratio was used to test the hypothesis that higher levels of debt induce firms to undertake riskier activities.[13] It also permitted the testing of hypotheses relating to levels of investments in flying equipment and safety outputs. One of the dreaded consequences of deregulation in the U.S. has been increased congestion at major airports. This trend followed from hub-and-spoke network

[13] See Brander and Lewis (1986).

design and was exacerbated by increased competition, which forced a number of airline mergers to allow the formation of such networks.[14] The spread of hub-and-spoke networks, which was accelerated by deregulation, along with a considerable increase in traffic due to that, resulted in levels of airport congestion that may be hazardous. Thus, data on aircraft movement at airports was added to the data base, so that control variables related to congestion were included in the study.

4.2 An Economic Framework for Understanding Safety

Airline safety cannot be considered as just another product characteristic, such as product quality. Because there are problems of observability and because there are threshold levels under which the market could not exist – since limits of insurability would be crossed – the optimal level of safety cannot be determined by the market place alone. If safety was just another product characteristic, some carriers would offer riskier but cheaper flights, while others would offer more expensive but safer trips. Rather, safety is a product feature that determines total market participation. If the probability of fatal accidents was above some threshold, called say s, consumers would not be willing to fly. Insurers would not be willing to insure such activities or could do so only at prohibitive rates.[15] For example, firms involved in rocket launching are experiencing problems in finding insurers. The market would then be in danger of vanishing. Economists could thus advocate the use of safety regulation to decrease the probability of loss and create markets for otherwise risky activities, thereby increasing societal welfare.

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14 See Brueckner and Spiller (1989).

15 See Berliner (1985).

More generally, problems of externalities and asymmetrical information alone would entice economists to recommend that the safety of airline operations be regulated. Here asymmetrical information mean that airline managers have more information on their safety activities than the safety authority. Because of potential economies of scale in acquiring information (setting standards, testing equipment, etc.,), economists would argue further that safety regulation is best handled by a central agency. Licensing, surveillance, monitoring, enforcing and international coordination are other arguments that favor a governmental agency. Also, the federal government has responsibilities in airport management and traffic control. This creates the opportunity to coordinate changes in economic regulation and safety standards with changes in the levels and performance of infrastructures.

What remains to be specified are the means by which safety regulation is most efficient in providing the socially desirable level of safety without presenting an undue burden. Because compliance with safety standards and level of care cannot be perfectly observed by regulators, there exists a problem of asymmetrical information that reduces the effectiveness of direct regulation. On the other hand, the incentives created by liability do not lead to socially optimal levels of safety, given the possibility that the parties would not be able to pay fully for harm done or would not be sued. With air crashes, this problem can be linked to the imperfect valuation of human life, where compensation may not fully reflect social cost. Also, some crashes over populated areas may imply externalities that are not fully compensated by insurers. Because of these problems of asymmetrical information and dilution of incentives, it has been shown that it is socially advantageous to use regulation and liability jointly.[16] The

[16] See Shavell (1984).

basic licensing requirements are based on those considerations.

Here in addition, we suggest that economic incentives and disincentives should be taken into account in the formulation of safety regulations. The empirical analysis of economic factors influencing accidents will determine to what extent these incentives could be used effectively. Particularly, it will verify whether financial variables are statistically significant to explain accident rates of individual firms.

Economic incentives to invest in safety may take the form of increases in traffic and in the ability to raise capital. An airline that is perceived to be safer than another could draw more passengers. In fact, some airlines have used the safety argument in their advertising. The effectiveness of this argument is tinted by problems of perception and asymmetrical information. It could be corrected by making public the records of accidents, incidents and penalties due to unsatisfactory compliance with safety standards. At the other end of the firm's structure, shareholders have seen stock prices go down in the aftermath of crashes, albeit temporarily.[17] One occurrence may not act as a strong signal of deficiency and does not have lasting effects, but repeated occurrences can be damaging to the ability of the firm to attract customers and thus to raise capital. Again here, public disclosure of safety records could be used to influence investors' decisions and discipline firms. In the presence of asymmetrical information and "rare" accidents, these economic incentives may influence precautionary activities. Under normal circumstances, we think however that firms would work to avoid the potential of death associated with a crash landing, and this might be a sufficient incentive for most to influence precautionary activities in an important way.

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[17] See Borenstein and Zimmerman (1988).

While economic disincentives are thought to be significant, the various means by which they operate are complex and not fully understood as the following presumed linkages indicate. Empirical identification of the more important factors is needed before a model of the firm's safety decisions can be ascertained; it was one of the aims of this study.

The principal contributing factors to fatal accidents in the U.S. are equipment failure, weather and pilot error.[18] The level of care exercised by firms may turn these sources of accidents into causes. Equipment failure may signal faulty maintenance, aging aircraft that may result from inadequate levels of investment in equipment, which, in turn, may depend on the firm's ability to raise capital. Moreover, a precarious financial position in terms of high debt/equity ratio may push firms to go for fast profits. In those instances, firms might be less likely to discourage departures in questionable weather. But profitability by itself does not guarantee high levels of care. However, higher wages associated with high profits may attract pilots of greater quality. A firm in a better financial position may be able to develop safety awareness programs. But a firm can improve its financial position by reducing safety expenses. Firm-specific effects in that area may be reduced in the future by the mandatory education program promoted by the government. Data on the firm's financial position obtained at a finer level than that used in U.S. studies will allow us to distinguish between these countervail effects.

This study provides a better picture of the relation between a firm's financial decisions and safety output in terms of a statistical analysis of the variables described in the next section. But we should emphasize that the statistical results of this study are still preliminary. Let

[18] See Oster and Zorn (1989).

us conclude this section by presenting the main financial variables considered at different stages of the study:

-*Ratio of current assets over current liabilities*: this is a liquidity measure; under asymmetrical information between carriers and the regulator, a higher ratio predicts higher investments.

-*Working capital*: current assets minus current liabilities. This is an alternative measure of liquidity.

-*Debt equity ratio*: under asymmetrical information, more debt reduces incentives for safety or increases incentives for risky activities.[19]

-*Cash flow*: it represents an essential aspect of a firm's financial performance or status (financing constraint on investment). It is often proposed for business evaluation by the method of discounted cash flow. This variable can be a substitute for operating margins. It has several advantages over operating margins since cash flow takes into account investment requirements and degrees of leverage.[20] Low cash flow means high marginal cost of capital and less investment in safety.[21] However, a more appropriate direct variable is:

-*Flight equipment maintenance expenditures*: this variable is used in the econometric estimation of this study along with *Working capital* and *Debt equity ratio*.

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19 See Brander-Lewis (1986) and Brander-Spencer (1989).

20 See Beard (1989).

21 See Fazzari et al. (1988).

5 Data, Sources, Variables and Correlation Analysis

5.1 Data and Sources

This section presents a synthesis of all the steps that have been undertaken in order to build the data set which contains economic, operational and safety information on Canadian carriers of levels 1, 2 and 3.

Economic information on carriers has been provided by Statistics Canada. It includes financial variables (balance sheet) as well as revenue and expenditure variables by carrier and on a quarterly basis from 1976 to 1988. In addition, Statistics Canada provided operational data on carriers. This category of variables includes, for example, the number of passengers, the number of departures, hours flown, etc... Finally, the safety record of carriers has been established with the help of the data set of the Transportation Safety Board of Canada. It consists mainly in the number of accidents and incidents by carrier and on a quarterly basis from 1976 to 1988. Transport Canada provided data on aircraft movements at different airports and on the carriers' areas of operation.

The data set described in this section was used in the statistical model in order to identify the determinants of accidents in the Canadian airline industry.

The data set has been created from five different data sources. From the first source come operating statistics. Variables in this category were used in order to measure the level of risk exposure experienced by the carriers. These variables have been provided on a quarterly basis from 1976 to 1988 for most of the Canadian carriers of levels 1, 2 and 3. Information specific to unit toll and charter services was available. For unit toll services, the variables

are: passengers, passenger-kilometres, tons of goods, ton-kilometres of goods, hours flown, departures, and kilometres flown. For charter services, the variables are: passengers, tons of goods, hours flown, departures, and kilometres flown.[22]

The second source of information was the statement of revenues and expenses. This source provides statistics on unit toll and charter revenues, expenditures for the maintenance of flight equipment, other expenditures on maintenance, total expenditures, operating incomes (total revenues minus total expenditures), taxes and interest payments. Here again, all the variables have been provided on a quarterly basis for most carriers of levels 1, 2 and 3 and for the period from 1976 to 1988.

The third source of information was the balance sheet of the carriers. Since this information was available only on an annual basis, the variables retained from the balance sheet were repeated four times a year in the final quarterly sample. The variables retained were: total current assets, total current liabilities, long-term debt and leases, shareholders' equities. These variables have been used in conjunction with the variables derived from the statement on revenues and expenses to establish the economic conditions under which carriers were operating.

The fourth source of information was the data set from the Transportation Safety Board on airline accidents. The information included in this data set has been used to compute the number of accidents on a quarterly basis and by carrier from 1976 to 1988.

Finally, the area of operation and congestion variables were built with the collaboration of the Aviation Statistics and Forecasts Branch of Transport Canada.

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[22] Information on departures and kilometres flown was not available for 1988.

These five sources of information have been merged together in order to create a single sample of quarterly observations. The final sample contains 3965 observations on approximately 100 Canadian carriers of levels 1, 2 and 3. Some observations have been deleted at different stages of the construction of the sample because of incorrect or incomplete information on several variables. Also, for some carriers, information was not available over the entire period of the study (1976–1988), which implies that, for many carriers, we did not have 52 observations (4 quarters, 13 years). This is partly due to airline mergers. Moreover, some carriers stopped their activities before 1988, while others started theirs after 1976. In the next section, we present a brief description of each variable defined for potential use in the statistical model and also some statistical features of the final sample in terms of these variables.

Additional modifications and deletions were necessary because a more careful examination of the data revealed several problems. Firstly, the more important problem was that, for most of the deleted observations, information on several variables was missing or inaccurate.[23] There is, of course, no guarantee that these deletions did not bias the estimates. However, one of the basic assumptions underlying the estimation of a model which explains the number of accidents is that the estimated coefficients were identical for all firms in the sample. Therefore, under this assumption, missing firms did not have particularities that distinguished them from other firms and, if it was the case, there was nothing to indicate this. Also, since we are interested in the statistical relationships between independent variables and the number

[23] For example, several firms have reported passengers but zero hour, kilometer or departure. Moreover, some firms have reported a negative number for total expenditures, flight equipment expenditures, total revenues and debt. We think that this kind of information is inconsistent.

of accidents rather than in the estimation of the overall level of accidents, we do not think that deletions could seriously alter our conclusions. Our sample still contains a very large number of carriers and we are confident that it is representative of the entire industry.

Secondly, since Statistics Canada did not collect data on departures and kilometres flown in 1988, we had to limit the final sample used in the econometric analysis to the period 1976–1987. As we shall see, these years are important for the final specification of the econometric model.

Thirdly, we changed the definition of the variable **CONG** in order to improve the statistical model. Thus, instead of **CONG** (percentage of departures at congested airports) we used **CONGT** and **CONGV** which are, respectively, the percentage of departures (unit-toll services) at the Toronto and Vancouver airports since 1984. Before 1984, **CONGT** and **CONGV** are set equal to zero. This will help to capture more accurately the congestion effect, if any. We also added in the data sample a time trend (**T**) which helped to capture the observed long-run improvement in safety.

Finally, we obtained information from Transport Canada to construct an area variable called **NORTH** which takes into account the effect of weather conditions on airline accidents. We understand that our definition may not be very accurate in measuring this type of effect. One interesting alternative is to identify airports which are located in any region of the country recognized as difficult for flying and then compute, for each carrier, the percentage of departures from these airports (like **CONGT** and **CONGV**). This new variable could then be used in conjunction with **NORTH**. We actually have the information on the number of departures (unit-toll services) by airport. The only additional information not yet available is

the number of departures (charter services) by airport and the list of airports located in those regions where the climate is inhospitable to aviation.

5.2 Variables and Descriptive Statistics

5.2.1 Accidents

This section presents a preliminary analysis of aircraft accident data provided by the Transportation Safety Board of Canada (hereafter TSB). The TSB provided us with data on aircraft incidents and accidents. However, because aircraft incidents have only been reported on a regular basis to the TSB since 1984, their description for our period of analysis (1976–1987) is more difficult to make. The present section will concentrate on aircraft accidents over the period 1976–1987. The next sub-section will discuss incidents. The TSB data are computerized information taken from the "Report of an Investigation of an Aircraft" form. This form contains all the information collected by a TSB investigator following an aircraft incident or accident.

Between 1976 and early 1989, **3799** commercial aircraft accidents were reported to the TSB. This figure includes accidents in Canada by Canadian and foreign commercial aircrafts and accidents in foreign countries by Canadian commercial aircrafts. From this population of accidents, a data set of **1797** accidents has been created. The remaining 2,002 accidents were not studied in detail since we had not enough information to include them in the data set. The accidents retained in the data set involve aircrafts registered in Canada which were carrying passengers or cargo over the period 1976–1988. Aircraft must be owned or leased by scheduled, charter or air taxi operators. In addition, only those accidents for which it was possible to identify the operator of the aircraft have been retained (for the moment, it is not

possible to identify the operator in **13** accidents). These selection criteria have been used in order to facilitate the merge of accident data with financial and operational data.

Main Characteristics of the Accident Data Set: **584** different names of operators (hereafter carriers) were reported in the data set created. This does not mean that **584** different carriers were involved in accidents since some of them had their names changed between 1976 and 1988. Therefore, the number of different carriers which were involved in accidents over the period of analysis was certainly less than **584**. It is not possible to obtain the exact number of carriers without a careful examination of the carriers' names.

Charter type operations were involved in **93.4%** of accidents, while scheduled type operations were involved in **4.0%** of accidents and air taxi in **2.6%**. Passengers were involved in **64.7%** of the accidents. However, **32.1%** of accidents have caused casualties (deaths or injuries). Serious injuries have been observed in **21.9%** of accidents. The average number of passengers per aircraft (including the crew) is **4.3**. The average number of deaths per accident is **0.4**, while the average number of passengers injured is **0.6**. In **97.0%** of accidents, the aircraft was substantially damaged or destroyed.

A total of **997** accidents (**55.5%**) occurred between 1976 and 1981 (a 6 year period) and over the following 7 years, "only" **800** accidents (**44.5%**) occurred. This last figure seems to indicate a slight decline in the number of accidents over the entire period. Finally, **44.7%** of accidents occurred in the summer, over a period of 4 months (June to September).

Merging Accident Data with Financial and Operation Data: In order to merge the data set of accidents with financial information and operating statistics, we first had to compute the number of accidents by carrier and on a quarterly basis. This first step was easy

to accomplish. However, to obtain a perfect match between the two sources of information, the key (the operator codes of carriers) must be the same for the two sources. Therefore, we had to build a key which took into account the changes in the names of carriers since 1976. Once this task had been done, we were able to merge adequately financial and operation data to accident data.

Statistics Canada provided us with financial and operating data which involved level 1, 2 and 3 carriers. Since our set of accidents was made up of all carriers, regardless of their level, the post-merged data set involved less than **1797** accidents. In fact, during the period 1976–87, only the accidents with financial and operation data of level 1, 2 and 3 carriers were available for the statistical analysis, that is, **530** accidents.

5.2.2 Incidents

Since 1976, **7717** commercial aircraft incidents have been reported to the **TSB**. This includes incidents in Canada by Canadian and foreign commercial aircraft and incidents in foreign countries by Canadian commercial aircraft. From this population of incidents, a data set of **4239** incidents has been created. The incidents retained in the data set involve aircraft registered in Canada which were carrying passengers or cargo over the period 1976–1988. The aircraft must be owned or leased by scheduled, charter or air taxi operators and only those incidents for which it was possible to identify the operator of the aircraft have been retained (it was not possible to identify the operator in **1304** incidents). In addition, incidents for which the type of operator (scheduled, charter, air taxi, etc.) and the load description variables (passengers, cargo, pesticides, etc.) were missing have been kept in the data set (these two variables were missing in nearly **93%** of the cases).

1110 different carrier names are listed in the data set created. Here again this does not mean that **1110** different carriers were involved in incidents, since some of them had their names changed between 1976 and 1988.

As reported in Table 1 below, an important proportion of incidents occurred after 1984. In fact, **64.8%** of the incidents listed in the data set occurred after 1984 (a five-year period) while **35.2%** occurred between 1976 and 1983 (an eight-year period). This last figure is consistent with the fact that prior to December 1st, 1984, there was no requirement to report incidents in Canada.

Also, unlike accidents, incidents seem to be less related to the time period of year (**33.7%** of the incidents listed in the data set occurred between June and September, while **44.7%** of the accidents occurred in the same period).

Table 1
Incidents 1976 — 1988

Year	*Number*	*%*
1976	157	3,7
1977	161	3,8
1978	178	4,2
1979	179	4,2
1980	247	5,8
1981	219	5,2
1982	150	3,5
1983	196	4,6
1984	221	5,2
1985	391	9,2
1986	514	12,1

Table 1
(Continued) Incidents 1976 — 1988

1987	717	16,9
1988	906	21,4

5.2.3 Aircraft Movement at Congested Airports in Canada

This section is about Canadian airlines of levels 1, 2 and 3 serving potentially congested airports in Canada. Three main airports have been considered: Toronto, Montréal-Dorval and Vancouver. In a previous report,[24] we presented a list which enumerates airlines serving those airports since 1976. Since airport congestion is a relatively new problem in Canada, we did not consider those three airports as being congested for the entire period (1976-1987). Congestion has been a more serious problem in Canada for the last five or six years, particularly in Toronto and Vancouver. This fact was taken into account in the analysis of the determinants of airline accidents. Table 2 presents the annual movements in three major airports in Canada and shows that aircraft movements at Dorval did not increase as much as at Toronto and Vancouver. Therefore, Dorval was not considered as a congested airport in the statistical analysis. According to Table 2, Dorval's increase has lagged Toronto's since 1983 (60% vs 67%). It is interesting to observe, however, that Dorval had the fastest increase since 1986, and has exceeded Toronto's increase since 1985.

Our theoretical section discussed in detail the potential effects of airport congestion on airline safety or airline accidents. While this problem is a crucial one in the United States (Gifford and Sinha, 1991), it is far less important in Canada at least for the moment. We

[24] All the interim reports are available upon request from Georges Dionne, C.R.T., Université de Montréal.

therefore expect a weaker link in Canada than in the United States between congestion and airline accidents.

Table 2

Aircraft movements at the Vancouver, Toronto and Montreal-Dorval Airports, 1976–1988

Year / Airport	*VANCOUVER*	*TORONTO*	*DORVAL*
1976	70 178	138 261	86 247
1977	70 756	135 686	80 444
1978	72 507	135 480	78 547
1979	82 028	144 054	79 919
1980	82 963	147 224	83 571
1981	80 169	148 045	82 236
1982	85 266	147 090	76 036
1983	79 759	144 194	74 649
1984	89 380	159 450	83 662
1985	102 354	179 151	84 658
1986	127 209	199 092	93 541
1987	136 105	209 387	100 763
1988	151 621	240 340	119 258
Source : Transport Canada			

5.2.4 Variables Retained for the Econometric Analysis

The following variables were retained for the econometric model.

5.2.4.1 Risk Exposure Variables

- Hours Flown (HOURS)

  The total number of hours flown on a quarterly basis and by carrier (unit-toll and charter). This is the most accurate variable for risk exposure. A positive sign is predicted for the coefficient.

Mean = 2 597.21

Std.Dev. = 6 826.19

- North (NORTH)

A dummy variable with NORTH=1, if the carrier has served regularly (50% or more of the activities) the designated Northern area (National Transportation Act, 1987). The variable is equal to zero otherwise. This variable will capture the effect of particular conditions of this region on airline safety. A positive sign is predicted.

Mean=0.225

Std.Dev.=0.417

5.2.4.2 Financial Variables

In order to take into account the three levels of carriers in the different econometric models, we used financial variables associated with each level. These variables are indicated by the letter i, i=1,2,3.

– Operating margin (OMARGi, i=1,2,3)

Operating margin is defined as $(1-\frac{\text{operating expenses}}{\text{operating revenues}})$ on a quarterly basis and by carrier. It is difficult to make a clear prediction for the sign of the estimated coefficient since the variable measures two conflicting effects. For the moment, we say that the sign is undetermined. A more detailed discussion can be found in the section presenting the econometric results.

	MEAN	*Std.Dev.*
OMARG1	0.032	0.088
OMARG2	0.063	0.154
OMARG3	-0.1059	0.944

– Working capital (WCi, i=1,2,3)

This is defined by: total current assets minus total current liabilities. This is a liquidity measure. A higher ratio should predict higher investments in the future. This is a good signal to obtain advantageous loans from banks. However, it may also reflect lower general expenditures on safety in the current period or the need for higher investments in safety equipment for the current period.

	MEAN	*Std.Dev.*
WC1	-55.86	2,092.1
WC2	-86.83	1,124.7
WC3	-68.88	2,315.01

– Debt Equity ratio (DE Ratioi, i=1,2,3)

This is the ratio of total long-term debt over shareholders' equity. Under asymmetrical information, more debt reduces incentives for safety or increases incentives for risky activities. A positive sign is predicted.

	MEAN	*Std.Dev.*
DE Ratio1	6.30	9.61
DE Ratio2	1.51	2.80
DE Ratio3	1.58	16.78

– Flight Equipment Maintenance Expenditures per Hour Flown (FEi, i=1,2,3)

This variable measures the total amount of expenditure on flight equipment maintenance divided by the number of hours flown. Quarterly information on this variable was available from 1981 to 1987. From 1976 to 1980, the information was available on an annual basis

only. Consequently, for that period, annual figures were converted to quarterly ones with the following formula:

FEi = (MEi/MEAi) *FEAi

where MEi is the quarterly level of expenditures on maintenance,

MEAi is the annual level of expenditures on maintenance,

FEAi is the annual level of expenditures on flight equipment maintenance divided by the number of hours flown.

A negative sign is predicted for this variable.

	MEAN	*Std.Dev.*
FE1	1539.13	886.78
FE2	751.56	567.10
FE3	215.87	220.09

5.2.4.3 Accident Data Variable

– Number of accidents (NACC)

This is the total number of accidents on a quarterly basis and by carrier from 1976 to 1987. The values of this variable range from 0 to 4 which justifies the use of count data econometric models. The number of accidents is 0 in 88,2% of sample observations.

Mean = 0.133670

Std.Dev. = 0.390075

5.2.4.4 Control Variables

– Time Trend (TIME)

This variable measures the variation of conditions that affect underlying risk over time. This is a year-specific time variable: 1 in 1976, 2 in 1977.... Since we introduced level specific variables for financial variables, the time trend variable controls mainly the evolution of technology over time. A negative sign is predicted.

– Congestion (CONGT, CONGV)

CONGT (CONGV) is the percentage of departures at the Toronto (Vancouver) airport after 1983. The variable is equal to zero otherwise. A positive sign is predicted.

VARIABLE	*MEAN*	*Std.Dev.*
CONGT	0.0027	0.0238
CONGV	0.0021	0.0269

– Speed (SPEED)

This is the ratio of total number of kilometres over total number of hours flown on a quarterly basis and by carrier. We use this variable as a proxy for the average type of aircraft owned by a carrier. A negative sign is predicted since, in general, jets are safer.

Mean = 200.84

Std.Dev. = 163.04

5.3 Correlation Analysis

In this section, we analyze the correlations between the number of accidents (NACC) and the variables that were used later in the different econometric estimations.

Table 3 presents the correlation coefficients between NACC and the different variables.

Table 3

Correlation Coefficients Between NACC and Variables Used in the Econometric Analysis. (N= 3965)

VARIABLE	*CORRELATION COEFFICIENT*[1]
HOURS	0.09309*
SPEED	-0.10250*
FE1	-0.00123
FE2	-0.03473
FE3	0.00597
OMARG1	0.00288
OMARG2	-0.01558
OMARG3	0.04714*
WC1	0.02321
WC2	-0.00584
WC3	0.01765
DE Ratio1	0.00593
DE Ratio2	-0.01292
DE Ratio3	-0.00556
CONGV	-0.00946
CONGT	-0.02107
NORTH	0.07993*

[1] Pearson correlation coefficient. An * indicates that the coefficient is statistically different from zero at a 1% level of confidence.

As seen in Table 3, the most relevant risk exposure variable is HOURS. The other candidates (departures, kilometres....) had very low correlation coefficients. The SPEED variable has a correlation coefficient almost equivalent (in absolute value) to that of HOURS.

SPEED will then represent an important control variable in the econometric analysis. Another important control variable is NORTH. However, congestion variables are not very

correlated with accidents. The same remark applies to the financial variables.

Let us note at this point that correlation coefficients should not be interpreted as all other things being equal effects (ceteris paribus). That is, correlation coefficients give indications about the statistical relationship that might exist between two variables, but they do not measure the effect of one variable on another, ceteris paribus. However, as we can see, correlation coefficients are useful to direct the specification of the different regression models.

As pointed out above, correlation coefficients are small for all financial variables (with one exception OMARG3) which seems to indicate that the links between the number of accidents (and, therefore, safety) and the financial situations of firms are weak. However, because of the above ceteris paribus statement, we will consider all these variables in the forthcoming econometric analysis.

6 Econometric Models

This section deals with the econometrics of accident distributions. It reviews the different models that will be useful to estimate the relative factors explaining the number of accidents in a given period of time. Since the number of accidents takes only nonnegative values, count data models are the appropriate tools for this type of analysis.

It is reasonable to suppose in the first stage of analysis that, for a given firm, the probability of being involved in an accident satisfies the following conditions: the probability of accident is proportional to the length of the period considered, the instantaneous probability of accident is constant throughout the period, the probability of having more than one accident in a period is small, and accidents are independent. In other words, letting k(t, t + dt) stand for the number of accidents occurring in the time interval from t to t + dt, it is reasonable to suppose that

$$p[k(t, t+dt) = 0] = 1 - \lambda\, dt + O(dt)$$

and that

$$p[k(t, t+dt) = 1] = \lambda\, dt + O(dt);$$

therefore,

$$p[k(t, t+dt) \geq 2] = O(dt) \text{ when } dt \to 0.$$

where λ is a parameter and $O(dt)$ is for higher order terms which are assumed to be negligible.

The Poisson distribution does satisfy the above conditions and will therefore be used as a first choice to represent the distribution of accidents. The probability that a firm will be involved in k accidents over t years is then:

$$p(k/t, \lambda) = \frac{e^{-\lambda t}(\lambda t)^k}{k!},$$

where λ is both the mean and variance of the distribution. However, using a Poisson distribution to represent the observed distribution of accidents for a group of firms supposes implicitly that all firms have the same probability of being involved in one or more accidents. This last feature is very restrictive. If, on the other hand, we assume that λ varies between firms and that, for a given firm, the distribution of accidents follows a Poisson distribution, then it will mathematically be convenient to suppose that λ is distributed as $f(\lambda)$,

$$f(\lambda) = \frac{\lambda^{a-1}\tau^a e^{-\tau}}{\Gamma(a)}, \ \tau > 0, \ a > 0,$$

that is, follows a Gamma density function with mean a/τ and variance a/τ^2, Γ(a) being the Gamma function. From the distribution of λ, the average probability of being involved in k accidents over t years or periods becomes the negative binomial distribution:

$$P(k/t, a, m) = \frac{\Gamma(k+a)}{k!\Gamma(a)} \left[\frac{a}{a+mt}\right]^a \left[\frac{mt}{a+mt}\right]^k,$$

where the mean is m = a/τ and the variance is (a/τ) (1 + 1/τ). If the distribution of accidents is better represented by the Poisson distribution, it would suggest that firms are homogeneous insofar as their respective probabilities of accident are concerned. This would imply, among other things, that differential insurance pricing or specific applications of regulatory policy based on past experience would have no supporting empirical evidence.

The above models do not permit the identification of factors that explain the distribution of accidents. It would be worthwhile to find out which firms' characteristics are responsible or significant. Moreover, allowing heterogeneity in the firms' probabilities of accident may make the basic Poisson model more attractive. We now look at both the Poisson and the negative binomial models with heterogeneous firms. In both cases, we will assume that

a firm's probability of accident depends on its characteristics: in the Poisson model, we assume that the distribution of accidents in which a firm is involved, remains a one-parameter distribution (hence, mean and variance are equal), while in the negative binomial case, we allow for overdispersion (a variance larger than the mean) in the distribution by assuming that the firms' characteristics leave some differences between the unexplained individual probabilities and that this unexplained portion follows a Gamma distribution. In a sense, the set of characteristics which the data allow us to define may not be rich enough to stick to the Poisson distribution with heterogeneous firms.

Let K_i be the number of accidents in which firm i is involved in a given period. Let us suppose that the assumptions underlying the one-parameter Poisson model are satisfied and moreover, that the function linking the parameter λ_i to the characteristics is

$$\lambda_i = exp(x_i\beta),$$

where β is a k x 1 vector of weights to be estimated. Then, the probability that firm i will be involved in k accidents is

$$p(K_i = k/x_i) = \frac{e^{-exp(x_i\beta)}exp(x_i\beta)^k}{k!}.$$

The mean and variance of K_i are both $\lambda_i = \exp(x_i\beta)$; note that the form exp(.) simply makes sure that λ_i is nonnegative. The likelihood function of the data (K_i, x_i) is given by

$$L(K;\beta) = \frac{\prod_{i=1}^{n} e^{-exp(x_i\beta)} \quad exp(x_i\beta)^{K_i}}{K_i!}.$$

Nancy Rose (1988) estimated the above model in her study of U.S. airline accidents. The Poisson model with firms' characteristics is restrictive in many ways. As we mentioned

above, the Poisson model rests on an assumption of independence of successive accidents. Hence, the probability that a firm will be involved in an accident in period t is independent of whether or not it was involved in an accident in t - 1 or more generally t' < t.

Another possibly restrictive assumption of the Poisson model is that, for a given firm, the conditional mean and conditional variance of the distribution are equal. The problem here is of a different nature from the previous one: it is basically an estimation problem since it may produce an underestimate of the variance (towards the mean) and hence too large student-t values, that is too many and too strongly significant individual characteristics. Moreover, the Poisson model may attach too small probabilities to the possibility that the number of accidents is two or more. Fortunately, there are relatively simple remedies for this second problem. The idea is, of course, to break the strong link between mean and variance. We noted above that one could generate a two-parameter distribution of accidents by allowing the individual λ_i to follow a gamma distribution. In the present case, although the λ_i are different from firm to firm, it remains that the conditional mean and conditional variance of each individual Poisson distribution are both equal to $\lambda_i = \exp(x_i \beta)$. Or course, allowing the λ_i to differ from each individual through the different vector x_i of characteristics may or may not be sufficient to explain adequately the overdispersion uncovered in the preceding subsection.

One way to introduce additional flexibility in the model is to suppose that the vector of characteristics x_i is not sufficient to capture the whole difference between firms and to assume that the additional unobserved characteristics can be modeled as a random addition μ_i to x_i, that is

$$\lambda_i = exp(x_i\beta + \mu_i),$$

with probability density function $h(\mu_i)$. Of course, μ_i may also represent pure randomness. Then, the marginal probability that the i-th firm will be involved in k accidents becomes:

$$\int P[k \mid t = 1, x_i, \mu_i] h(\mu_i) d\mu_i$$

$$= \int \frac{e^{-(x_i\beta+\mu_i)} exp(x_i\beta + \mu_i)^k}{k!} \; h(\mu_i) d\mu_i,$$

which is the general form of the Compound Poisson distribution: different specifications of $h(\mu_i)$ lead to different particular cases.

The particular form we will consider here is the negative binomial distribution obtained by writing $\lambda_i = \exp(x_i\beta + \mu_i) = \exp(x_i\beta)\epsilon_i$ and assuming that $\epsilon_i = \exp(\mu_i)$ follows a gamma density

$$f(\epsilon) = \frac{\epsilon^{a-1} e^{-a\epsilon} a^a}{\Gamma(a)},$$

with a mean of 1 (the mean of μ_i is assumed equal to 0) and a variance 1/a. Integrating the expression for the distribution of accidents above, we find

$$P(K_i = k \mid x_i) = \frac{\Gamma(k+a)}{k!\Gamma(a)} \left(\frac{exp(x_i\beta)}{a}\right)^k \left(1 + \frac{exp(x_i\beta)}{a}\right)^{-(k+a)},$$

which is the expression for the negative binomial distribution with parameters a and $\exp(x_i\beta)$; its mean is $E(K_i) = \exp(x_i\beta)$ and its variance $V(K_i) = \exp(x_i\beta)[1 + \exp(x_i\beta)/a] = E(\lambda_i)[1 + E(\lambda_i)\, VAR(\epsilon)]$. Hence, the variance is a strictly convex increasing function of the mean: the variance/mean ratio is a linear function of the mean. As mentioned above, Nancy Rose (1988) limited her statistical analysis to the Poisson regression which may be very restrictive since it assumes implicitly that the mean is equal to the variance. However, the variance of her sample differs from the mean and the negative binomial model might have been more

appropriate. Dionne and Vanasse (1988, 1989) and Boyer, Dionne and Vanasse (1990) have estimated the above models for car accidents. They showed that the negative binomial model with a regression component produces a reasonable approximation of the true distribution of accidents. Different statistical tests rejected the Poisson models (with and without a regression component) and the negative binomial model without individual characteristics.

It is not clear that similar results will be obtained in the next section. Part of the research investigated in detail the applicability of the above models to airline accidents.

7 Econometric Results

Table 4 presents the results from four different econometric specifications. Two estimated models (Models 3 and 4) do not reject the assumption of the Poisson distribution since the overdispersion parameter (1/a) is not significantly different from zero. This result implies that there is no overdispersion under these two specifications. In other words, the conditional variance (conditional to the model specification) is not significantly greater than the conditional mean in Models 3 and 4. More specifically, the mean of the sample is 0.13 while its variance is equal to 0.1522. The estimated mean from Model 3 is 0.13 while its estimated variance is 0.14. For Model 4 the corresponding results are 0.13 and 0.14, respectively. Model 5 presents the estimation of the Poisson model when the parameter (1/a) is not estimated. The results are very similar to those of Model 4.

However, the results from Models 1 and 2 show that the conditional variances are significantly greater than the respective conditional means (1/a is statistically different from zero). This conditional overdispersion is due to incomplete specifications of Models 1 and 2 in the sense that important significant variables[25] are not included in Models 1 and 2. In other words, Models 1 and 2 contain specification errors.

The results of Model 1 can be compared to those of Table 2 in Nancy Rose's article where the operating margin coefficient for small firms ranges from -2.04 to -2.77 and is statistically different from zero at a 10 percent level or better. The coefficient of medium firms (-1.803) is statistically different from zero only in her fix effect specification (column 3) which is the most comparable to that of our Model 1 in Table 4. In Rose's study,

[25] When both models were estimated without a regression component, we rejected the Poisson model.

the estimated coefficients are never significant for large firms, a result that we obtain for airlines of levels 1 and 2 in our study. However, the coefficient of OMARG3 is *positive* and statistically different from zero which means that increased profitability for carriers of level 3 is associated with more accidents. Although this result can be useful for the administration of public safety, it does not necessarily indicate that firms with large operating margins spend less resources in safety since different levels of operating margins can be explained by many variables other than maintenance expenditures. Moreover, the interpretation of this variable is not straightforward. Do higher operating margins mean that airlines have more funds for safety or do they mean that airlines reduced their maintenance expenditures during the period under study? Since we use operating margins of the current period (without any lags) both interpretations are equally valid.

A more precise variable, to measure the correspondence between the number of accidents in a given period as a function of different airlines' safety efforts, is the level of maintenance expenditures (FEi). This variable is used in Model 2.

Table 4
Econometric Results on Total Accidents, Canadian Airlines, Levels 1, 2, 3, 1976–1987 (N=3965)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	-1.14 (-10.34)	-1.15 (-8.09)	-1.27 (-8.89)	-1.29 (-8.90)	-1.30 (-9.07)
HOURS	0.329 E-04 (7.28)	0.777 E-04 (6.88)	0.101 E-03 (6.75)	0.10 E-03 (6.56)	0.11 E-03 (6.94)
SPEED	-0.278 E-02 (-8.53)	-0.228 E-02 (-6.43)	-0.192 E-02 (-5.45)	-0.19 E-02 (-5.37)	-0.19 E-02 -(5.46)
FE1		-0.268 E-02 (-4.53)	-0.52 E-02 (-4.51)	-0.58 E-02 (-4.26)	-0.61 E-02 -(4.62)
FE2		-0.72 E-03 (-2.16)	-0.89 E-03 (-2.60)	-0.10 E-02 (-2.51)	-0.10 E-02 (-2.56)
FE3		-0.45 E-03 (-1.82)	-0.46 E-03 (-1.85)	-0.43 E-03 (-1.75)	-0.43 E-03 (-1.76)
OMARG1	-2.93 (-0.91)				
OMARG2	-0.816 (-0.648)				
OMARG3	0.416 (3.81)				
WC1			0.16 E-03 (3.40)	0.18 E-03 (3.36)	0.20 E-03 (3.75)
WC2			-0.22 E-03 (-0.76)	-0.27 E-03 (-0.89)	-0.28 E-03 (-0.92)
WC3			0.19 E-03 (1.74)	0.17 E-03 (1.47)	0.15 E-03 (1.36)
DE Ratio1				0.327 E-01 (0.89)	0.38 E-01 (1.08)
DE Ratio2				0.497 E-01 (0.44)	0.49 E-01 (0.44)
DE Ratio3				-0.317 E-02 (-0.73)	-0.324 E-02 (-0.75)
CONG V	1.07 (0.53)	0.97 (0.47)	1.09 (0.54)	1.05 (0.52)	1.05 (0.52)
CONG T	0.29 (0.106)	-0.41 (-0.14)	-0.41 (-0.14)	-0.31 (-0.11)	-0.35 (-0.12)
TIME	-0.91 E-01 (-7.08)	-0.97 E-01 (-7.34)	-0.98 E-01 (-7.37)	-0.96 E-01 (-7.23)	-0.96 E-01 (-7.35)
NORTH	0.54 (5.50)	0.48 (4.87)	0.49 (4.97)	0.48 (4.98)	0.48 (5.03)

Table 4
(Continued) Econometric Results on Total Accidents, Canadian Airlines, Levels 1, 2, 3, 1976–1987 (N=3965)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
1/a	0.3838 (2.16)	0.4527 (2.44)	0.1833 (1.19)	0.1634 (1.08)	
Log Likelihood	-1532	-1524	-1513	-1512	-1513
Log Likelihood Ratio	197.04	211.92	234.48	236.36	261.00

Note: t-statistic in parentheses. The parameters are statistically different from zero when the t-statistic is greater than 1.645 at a 10% confidence level, 1.960 at 5% and 2.576 at 1%. The econometric estimation of Models 4 and 5 were made with 3961 observations since the data indicate that one firm has a negative debt for a given year (or four quarters). 1/a is the overdispersion parameter of the Negative Binomial model. When this parameter is positive and statistically different from zero this means that the conditional variance is greater than the conditional mean. The Log Likelihood Ratio statistic is computed as follows:
$-\ 2(LL(C)-LL(K))$ where LL(C) is the Log Likelihood of the regression limited to a constant term and LL(K) is the Log-Likelihood of the regression with K β– coefficients. The statistic is distributed as a χ^2 with K degrees of freedom. All the Log Likelihood Ratio values presented in the table are statistically different from zero which means that the five regressions are statistically significant.

We observe from Table 4, column 2, that the coefficient of this variable is negative and statistically different from zero for the three levels of carriers examined. This result is very important and, to our knowledge, was not published in any other study. It first shows precisely that the variable operating margins is not a good proxy for safety activities. It also indicates that, even if safety is regulated in such a manner that accidents are independent of economic considerations, Canadian airlines do affect their levels of accidents by modifying their levels of maintenance expenditures. In other words, even under strict safety regulations, firms seem to trade-off ex-ante benefits with costs of accidents. From Table 4, we also see that the addition of a variable that measures the working capital (or the liquidity) of the firm (WCi in Model 3) does not significantly affect the results.

Moreover, the coefficient of the working capital variable is significantly different from zero for the two levels, 1 and 3. Nancy Rose obtained a positive sign for that variable in her incident analysis (see her Table 3, column 3). Again, two interpretations are possible for a positive sign. The level of liquidity can be high because firms did not spend enough on safety in the current period or because firms are making financial reserves for future investments since the existing equipment is old or dangerous. In order to verify how investments are important, we added the debt equity ratio in the analysis (DE Ratio i, i=1, 2, 3 in Model 4). But more importantly, this variable is used as a proxy for the incentives for safety in corporations. Recent theoretical models of managers' behaviors under asymmetrical information show that managers take riskier activities when the debt/equity ratio is high. However, the statistical results of Model 4 are not consistent with these theoretical contributions since the DE Ratio i variables are not statistically significant.

All the above results were obtained when appropriate control variables were introduced. Since accidents are rare random events, many other factors than those used in the above econometric models and associated with particular accidents (such as weather, type of aircrafts, pilot behavior,... that we find on accident reports) may have been the real causes of the events. However, this information on accident reports cannot be used in the different models of Table 4 since we do not have information on the average conditions when there is no accident. We introduced some proxy variables for risk exposure such as HOURS and NORTH and other control variables such as SPEED, CONGV, CONGT. The TIME variable was used to take into account the evolution of the safety technology over time. As we can see, its coefficient is significant at a 1% confidence level with the appropriate sign. The coefficients are very

stable from one model to the other. The same comment applies to the variable NORTH which takes into account the particular operating conditions in the Northern region designated in 1987. Nancy Rose obtained similar results for her time and Alaska variables.

The congestion variables are not significantly different from zero. Two other significant variables were introduced as control variables, HOURS and SPEED. Contrarily to Nancy Rose, we did not use the number of departures since the preliminary results indicated that total hours is more accurate. The variable SPEED was introduced as a proxy for the different types of airplanes.

Tables 5 and 6 provide a test of our analysis. Table 5 presents the observations of accidents during the period 1976–1987 and the predictions from the estimated model (Model 3 in Table 4). Overall, the estimated model predicts 527 accidents for the 3965 observations used in the econometric estimations during the period of analysis, while 530 were observed for the same sample of firms. The χ^2 test shows that the overall prediction and its distribution cannot be rejected at a 10% confidence level which means that we do not reject the prediction from the Negative Binomial model at this level of confidence.

Table 6 presents similar results for Model 4. Again the Negative Binomial model predicts 527 accidents while 530 where observed and the model is not rejected at a 10% confidence level. We also reestimated Model 4 without the parameter (1/a) since it was not statistically significant. This yields the Poisson model (Model 5 in Table 4). It is interesting to observe, from Table 6, that the Poisson model predicts 528 accidents in total. According to the χ^2 test, we do not reject the prediction of the Poisson model at a 10% confidence level. We conclude that the Poisson model produces a reasonable approximation of the true distribution

of airline accidents in Canada for the period 1976–1987.

Table 5.
Accident Predictions vs. Accident Observations
Model 3 (3965 observations)

Number of accidents by airlines in a given period	Observations of airlines	Predictions of airlines Negative binomial model
0	3498	3496.14
1	411	417.59
2	51	43.80
3	3	5.73
4+	2	1.14
Total accidents	530	527

$\chi^2 = 1.797 < \chi^2_{1,90} = 2.71$

Table 6.
Accident Predictions vs. Accident Observations
Model 4 (3961 observations)

Number of accidents by airlines in a given period	Observations of airlines	Predictions of airlines Negative binomial model	Predictions of airlines Poisson model
0	3494	3491.49	3484.73
1	411	418.69	429.79
2	51	43.57	40.82
3	3	5.61	4.54
4+	2	1.08	0.78
Total accidents	530	527	528
		$\chi^2 = 1.86$ $\chi^2_{1,90} = 2.71$	$\chi^2 = 3.46$ $\chi^2_{2,90} = 4.61$

Note : Expected frequency in each class has to be greater than 5 for the χ^2 test. We grouped together classes 4 and 5 for both distributions which yielded $\chi^2_{4-2-1,90}$ for the Negative binomial model (2 parameters) and $\chi^2_{4-1-1,90}$ for the Poisson model (1 parameter).

8 Conclusion

In this study we have shown that some financial variables are significant to explain the distribution of airline accidents in Canada during the period 1976–1987. Particularly, the econometric results indicate that both Flight Equipment Maintenance Expenditures (FEi) and Working Capital (WCi) variables have statistically significant effects on the accident frequency. This means that airlines' financial conditions affected their safety choices during that period. These preliminary results seem to indicate that Canadian carriers trade off safety with other activities in a period characterized by both a strong regulation of aviation safety and an economic regulation of the industry. The statistical results also indicate clearly that the Designated Northern Area (identified by the variable NORTH) represents a more dangerous region for flying and that the type of aircrafts (measured by the proxy SPEED) is a significant explanatory factor of airline accidents. Other control variables in the models such as time and hours flown are also significant.

Since the period of analysis ended in 1987, it is difficult to propose any strong recommendation for public policy based on the results of financial variables analyses, although they can be useful for the discussion of future modifications of the regulatory scheme on aviation safety in Canada. However, the results of the different models indicate that financial variables are sufficient to assume that airline accidents follow a Poisson distribution and eliminate the specification error implied by the Negative Binomial model. This means that financial variables are important in order to understand the distribution of airline accidents and that they should be considered seriously in any discussion of safety regulation, particularly in an environment of asymmetrical information on safety activities between the regulator and carriers.

In many studies and forums, it has been indicated that economic deregulation of the airline industry might introduce a negative impact on safety. The traditional argument was that deregulation would reduce the profitability of air carriers and, consequently, carriers' safety budgets. The results of this report do not establish a strong statistical link between profitability (or operating margin which is a measure of profitability before capital expenses and taxes) and accidents and show that other financial variables are more appropriate measures of the statistical relationship between accidents and financial conditions. They also show that, even in the different economic regulatory environments for the period studied, financial variables were significant.

The result from the NORTH variable indicates, without any ambiguity, that more attention should be focussed on the safety conditions in that area. The same conclusion applies to the SPEED variable, but more investigation is needed to determine, in detail, the types of aircrafts that are more safe.

Many extensions to this research are possible. They involve activities at three levels:

1. As indicated in the presentation of the econometric results, these results are preliminary and cannot be used directly for public policy purposes. They correspond to the time research available between the date we received the final data set and now, which represents a relatively short period. Some variables were not studied in detail. For example, it is possible to pursue research on some financial variables and on future interpretations of the financial results. As discussed in the text, the econometric results can be consistent with different explanations. Particularly, it is not clear yet that some current financial variables reflect the current activities of safety or signal future activities.

One such example is Working capital. Before recommending that the regulator should use this measure of liquidity to evaluate private safety activities, more research is needed to understand its real interpretation in terms of safety. More research can also be done in order to introduce some proxies for the quality of the crews and particularly, the pilots. These suggestions of research and any other suggestions on future use of the actual data set would not be very costly in time since the data set is now built, but should produce more definitive conclusions than those suggested in this report.

2. Another type of extension concerns added information to the actual data set. In this report we were not able to use the 1988 data since it does not contain information on departures and kilometres, data necessary for the construction of variables such as SPEED, CONGT and CONGV.

   Statistics Canada no longer collects this information since it does not seem to be useful in the absence of economic regulation. However, as discussed above, these statistical variables are important for safety regulation and we recommend that Statistics Canada reconsider the possibility of collecting statistical information on these variables. More generally, it could be very useful to extend the data set of this study to 1991 in order to evaluate the effect of the 1987's reform on aviation safety (National Transportation Act, 1987).

3. Finally, we proposed an economic framework for understanding safety. We indicated that the econometric results on financial variables would be important to test the relevance of the proposed framework. We verified that, indeed, some financial variables have a

significant effect on the frequency of accidents. A further step is to be more specific on the applicability of the framework for the administration of public safety in Canada and to show how the negative effects of asymmetrical information on safety between the regulator and the carriers can be reduced.

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